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MADISON LAKE, BLUE EARTH COUNTY, MINNESOTA

Pacific Northwest Environmental Research Laboratory

Prepared for:

National Environmental Research Center
Minnesota Pollution Control Agency
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December 1974

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NATIONAL EUTROPHICATION SURVEY

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16. ABSTRACT
Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivded according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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I

REPORT
ON
MADISON LAKE
BLUE EARTH COUNTY
MINNESOTA

EPA REGION V

WORKING PAPER No. 108

WITH THE COOPERATION OF THE

MINNESOTA POLLUTION CONTROL AGENCY

AND THE

MINNESOTA NATIONAL GUARD

DECEMBER, 1974

II

CONTENTS

	Page
Foreword	ii
List of Minnesota Study Lakes	iv, v
Lake and Drainage Area Map	vi
Sections	
I. Conclusions	1
II. Lake and Drainage Basin Characteristics	3
III. Lake Water Quality Summary	4
IV. Nutrient Loadings	9
V. Literature Reviewed	14
VI. Appendices	15

FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC AFPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's fresh water lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the Minnesota Pollution Control Agency for professional involvement and to the Minnesota National Guard for conducting the tributary sampling phase of the Survey.

Grant J. Merritt, Director of the Minnesota Pollution Control Agency, John F. McGuire, Chief, and Joel G. Schilling, Biologist, of the Section of Surface and Groundwater, Division of Water Quality, provided invaluable lake documentation and counsel during the course of the Survey; and the staff of the Section of Municipal Works, Division of Water Quality, were most helpful in identifying point sources and soliciting municipal participation in the Survey.

Major General Chester J. Moeglein, the Adjutant General of Minnesota, and Project Officer Major Adrian Beltrand, who directed the volunteer efforts of the Minnesota National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

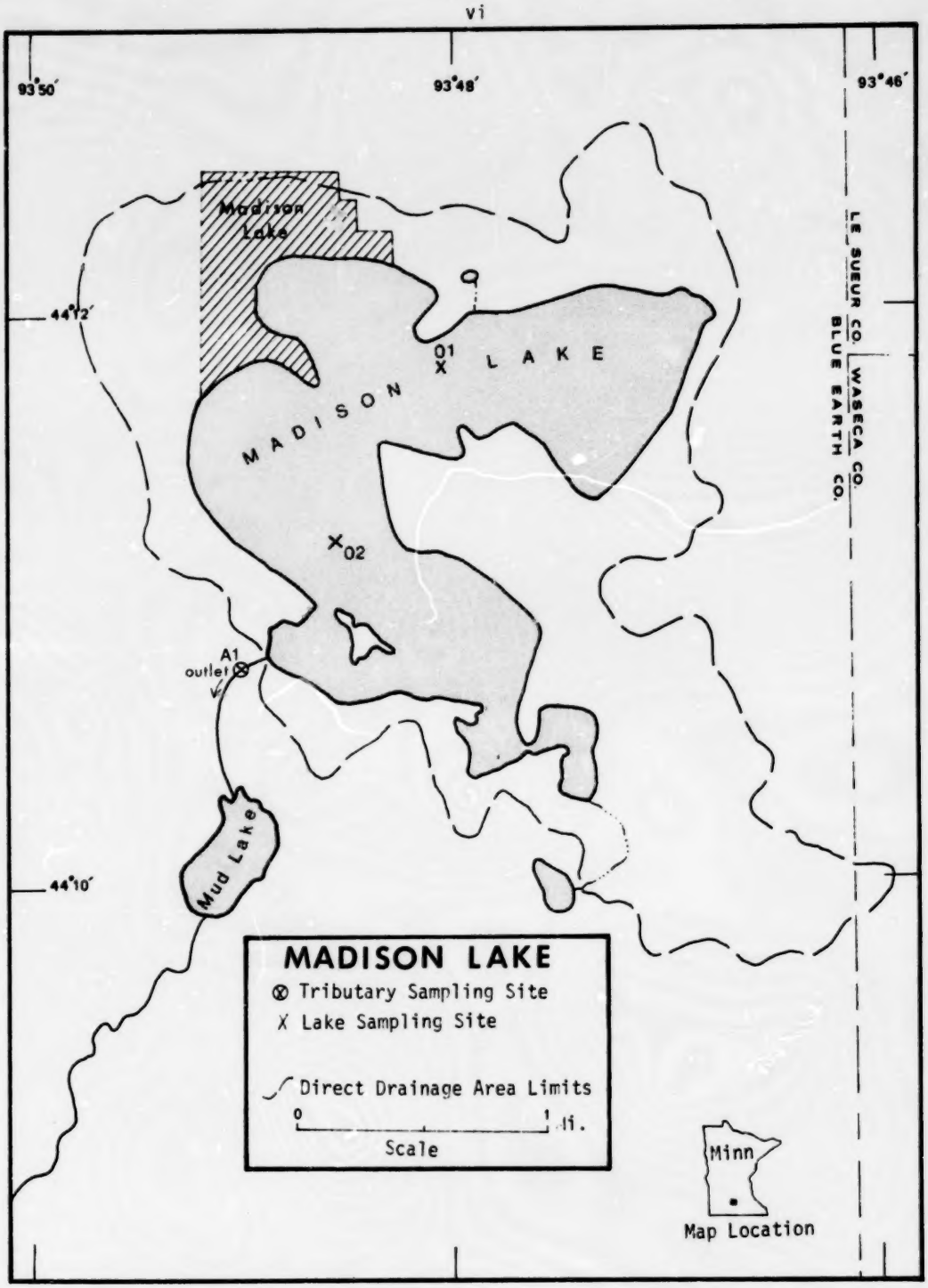
NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF MINNESOTA

LAKE NAME	COUNTY
Albert Lea	Freeborn
Andrusia	Beltrami
Badger	Polk
Bartlett	Koochiching
Bear	Freeborn
Bemidji	Beltrami
Big	Stearns
Big Stone	Big Stone, MN; Roberts, Grant, SD
Birch	Cass
Blackduck	Beltrami
Blackhoof	Crow Wing
Budd	Martin
Buffalo	Wright
Calhoun	Hennepin
Carlos	Douglas
Carrigan	Wright
Cass	Beltrami, Cass
Clearwater	Wright, Stearns
Cokato	Wright
Cranberry	Crow Wing
Darling	Douglas
Elbow	St. Louis
Embarass	St. Louis
Fall	Lake
Forest	Washington
Green	Kandiyohi
Gull	Cass
Heron	Jackson
Leech	Cass
Le Homme Dieu	Douglas
Lily	Blue Earth
Little	Grant
Lost	St. Louis

LAKE NAME	COUNTY
Madison	Blue Earth
Malmedal	Pope
Mashkenode	St. Louis
McQuade	St. Louis
Minnetonka	Hennepin
Minnewaska	Pope
Mud	Itasca
Nest	Kandiyohi
Pelican	St. Louis
Pepin	Goodhue, Wabasha, MN; Pierce, Pepin, WI
Rabbit	Crow Wing
Sakatah	Le Sueur
Shagawa	St. Louis
Silver	McLeod
Six Mile	St. Louis
Spring	Washington, Dakota
St. Croix	Washington, MN; St. Croix, Pierce, WI
St. Louis Bay	St. Louis, MN; Douglas, WI
Superior Bay	St. Louis, MN; Douglas, WI
Swan	Itasca
Trace	Todd
Trout	Itasca
Wagonga	Kandiyohi
Wallmark	Chisago
White Bear	Washington
Winona	Douglas
Wolf	Beltrami, Hubbard
Woodcock	Kandiyohi
Zumbro	Olmstead, Wabasha


93°50'
93°48'
93°46'
44°12'
44°10'
Madison Lake
MADISON LAKE
01
02
A1
outlet
Mud Lake
LE SUEUR CO.
WASECA CO.
BLUE EARTH CO.
MADISON LAKE
Tributary Sampling Site
Lake Sampling Site
Direct Drainage Area Limits
0
1 mi.
Scale
Minn
Map Location

MADISON LAKE

STORET NO. 2750

I. CONCLUSIONS

A. Trophic Condition:

Survey data show that Madison Lake is eutrophic. Of the 60 Minnesota lakes sampled in the fall of 1972, when essentially all were well-mixed, 25 had less mean total phosphorus, 23 had less mean dissolved phosphorus, and 49 had less mean inorganic nitrogen. Of the 80 Minnesota lakes sampled, 45 had less mean chlorophyll a, and 41 had greater Secchi disc transparency.

Survey limnologists noted poor water quality conditions on all sampling visits. Algal blooms, suspended solids, and anaerobic hypolimnetic conditions were observed.

B. Rate-Limiting Nutrient:

Results of the algal assay indicate that phosphorus was the limiting nutrient at the time the sample was collected. The lake data indicate phosphorus limitation during October and nitrogen limitation during July and August.

C. Nutrient Controllability:

1. Point sources--During the sampling year, Madison Lake received a total phosphorus load at a rate about 1.6 times the rate proposed by Vollenweider (in press) as "dangerous"; i.e., a eutrophic rate (see page 13).

The Minnesota Pollution Control Agency has stipulated with the Village of Madison for the construction of a wastewater treatment plant which will discharge to the LeSueur River. When this facility becomes operational, the phosphorus loading rate of Madison Lake will be reduced to about 1.8 lbs/acre/yr or about 0.19 $g/m^2/yr$. The reduced rate will be less than the eutrophic rate and should result in a significant improvement in the trophic condition of the lake.

2. Non-point sources--It is estimated that non-point sources contributed about 56% of the total phosphorus load to Madison Lake during the sampling year.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry†:

1. Surface area: 1,113 acres.
2. Mean depth: 13 feet.
3. Maximum depth: 59 feet.
4. Volume: 14,469 acre/feet.
5. Mean hydraulic retention time: 3.3 years.

B. Tributary and Outlet:
(See Appendix A for flow data)

1. Tributaries -

	Drainage area*	Mean flow*
No major tributaries	-	-
Minor tributaries & immediate drainage -	22.1 mi^2	6.1 cfs
Total	22.1 mi^2	6.1 cfs

2. Outlet -

Unnamed stream (A-1)	23.8 mi^2**	6.1 cfs

C. Precipitation***:

1. Year of sampling: 28.7 inches.
2. Mean annual: 28.3 inches.

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† DNR lake survey map (1970); mean depth by random-dot method.
* Drainage areas are accurate within ±5%; mean daily flows are accurate within ±10%; and ungaged flows are accurate within ±10 to 25% for drainage areas greater than 10 mi^2.
** Includes area of lake.
*** See Working Paper No. 1, "Survey Methods".

III. LAKE WATER QUALITY SUMMARY

Madison Lake was sampled three times during the open-water season of 1972 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from two stations on the lake and usually from two or more depths at each station (see map, page vi). During each visit, a single depth-integrated (15 feet or near bottom to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the last visit, a single five-gallon depth-integrated sample was composited for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll a analysis. The maximum depths sampled were 15 feet at station 1 and 31 feet at station 2.

The results obtained are presented in full in Appendix B, and the data for the fall sampling period, when the lake essentially was well-mixed, are summarized below. Note, however, the Secchi disc summary is based on all values.

For differences in the various parameters at the other sampling times, refer to Appendix B.

A. Physical and chemical characteristics:

Parameter	Minimum	Mean	Median	Maximum
		FALL VALUES (10/29/72)		
Temperature (Cent.)	6.1	6.7	7.0	7.0
Dissolved oxygen (mg/l)	10.4	10.8	10.8	11.3
Conductivity (μmhos)	310	321	320	330
pH (units)	8.1	8.2	8.2	8.2
Alkalinity (mg/l)	131	132	131	134
Total P (mg/l)	0.036	0.047	0.045	0.058
Dissolved P (mg/l)	0.016	0.022	0.022	0.026
NO_2 + NO_3 (mg/l)	0.170	0.180	0.180	0.190
Ammonia (mg/l)	0.750	0.789	0.800	0.830
		ALL VALUES		
Secchi disc (inches)	27	34	32	46

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Number per ml
07/01/72	1. Lyngbya	7,444
	2. Anabaena	4,060
	3. Flagellates	2,782
	4. Microcystis	677
	5. Raphidiopsis	602
	Other genera	4,435
	Total	20,000
08/30/72	1. Lyngbya	6,113
	2. Dictyosphaerium	1,623
	3. Merismopedia	1,358
	4. Flagellates	1,207
	5. Anabaena	566
	Other genera	2,605
	Total	13,472
10/24/72	1. Anabaena	5,075
	2. Chroococcus	1,357
	3. Synedra	704
	4. Cryptomonas	653
	5. Kirchneriella	502
	Other genera	2,965
	Total	11,256

2. Chlorophyll a -
(Because of instrumentation problems during the 1972 sampling, the following values may be in error by plus or minus 20 percent.)

Sampling Date	Station Number	Chlorophyll a (µg/l)
07/01/72	01	61.4
	02	33.3
08/30/72	01	19.8
	02	13.8
10/29/72	01	27.2
	02	29.3

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.020	0.750	3.8
0.005 P	0.025	0.750	6.4
0.010 P	0.030	0.750	8.0
0.020 P	0.040	0.750	11.7
0.050 P	0.070	0.750	17.6
0.050 P + 10.0 N	0.070	10.750	24.0
10.0 N	0.020	10.750	3.1

2. Discussion -

The control yield of the assay alga, Selenastrum capricornutum, indicates that the potential primary productivity of Madison Lake was somewhat high at the time the sample was collected. Also, the increased yields with increased levels of phosphorus indicate phosphorus limitation at that time (note the addition of only nitrogen did not result in a significantly different yield than that of the control). However, the lake data indicate nitrogen limitation during July and August (N/P ratios were 12/1 and 11/1, respectively, and nitrogen limitation would be expected).

IV. NUTRIENT LOADINGS
(See Appendix C for data)

For the determination of nutrient loadings, the Minnesota National Guard collected monthly near-surface grab samples from the tributary site indicated on the map (page vi). Sampling was begun in October, 1972, and was completed in August, 1973.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the Minnesota District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

In this report, the outlet nutrient loads were determined by using a modification of a U.S. Geological Survey computer program for calculating stream loadings*. Nutrient loadings for unsampled "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated by using the nutrient loads, in lbs/mi^2/year, in a tributary to nearby Lily Lake at station B-1 and multiplying by the ZZ area in mi^2.

The nutrient loads of the Village of Madison Lake were estimated at 2.5 lbs P and 7.5 lbs N/capita/year. The Madison Lake Creamery loads were calculated on water use (20,000 gal/month; Miller, 1961) and typical creamery wastewater nutrient concentrations (50 mg/l P and 70 mg/l N; Boydston, 1973).

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* See Working Paper No. 1.

A. Waste Sources:

1. Known municipal† -

Name	Pop. Served	Treatment	Mean Flow (mgd)	Receiving Water
Madison	587	none*	0.059**	Madison Lake

2. Known industrial*** -

Name	Product	Treatment	Mean Flow (mgd)	Receiving Water
Madison Lake Creamery	butter	none	0.001	Madison Lake

† Anonymous, 1974.
* Partial collection system but no treatment; septic tank effluent and raw sewage are discharged to Lake Madison.
** Estimated at 100 gal/capita/day.
*** Miller, 1961.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
None	-	-
b. Minor tributaries & immediate drainage (non-point load) -	1,790	50.8
c. Known municipal STP's -		
None	-	-
d. Septic tanks, Madison Lake -	1,470	41.6
e. Known industrial -		
Madison Lake Creamery	100	2.8
f. Direct precipitation* -	170	4.8
Total	3,530	100.0

2. Outputs -

Lake outlet - Unnamed Stream (A-1) 850

3. Net annual P accumulation - 2,680 pounds

* See Working Paper No. 1.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	lbs N/yr	% of total
a. Tributaries (non-point load) -		
None	-	-
b. Minor tributaries & immediate drainage (non-point load) -	95,600	86.2
c. Known municipal STP's -		
None	-	-
d. Septic tanks, Madison Lake -	4,400	4.0
e. Known industrial -		
Madison Lake Creamery	140	0.1
f. Direct precipitation* -	10,720	9.7
Total	110,860	100.0

2. Outputs -

Lake outlet - Unnamed Stream (A-1) 42,670

3. Net annual N accumulation - 68,190 pounds

* See Working Paper No. 1.

D. Yearly Loading Rates:

In the following table, the existing phosphorus loading rates are compared to those proposed by Vollenweider (in press). Essentially, his "dangerous" rate is the rate at which the receiving waters would become eutrophic or remain eutrophic; his "permissible" rate is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic rate would be considered one between "dangerous" and "permissible".

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	3.2	2.4	99.6	61.3
grams/m^2/yr	0.36	0.27	11.2	6.9

Vollenweider loading rates for phosphorus ($g/m^2/yr$) based on mean depth and mean hydraulic retention time of Madison Lake:

"Dangerous" (eutrophic rate)	0.22
"Permissible" (oligotrophic rate)	0.11

V. LITERATURE REVIEWED

Anonymous, 1974. Wastewater disposal facilities inventory. MPCA, Minneapolis.

Boydston, James R., 1973. Personal communication (typical nutrient concentrations in milk-processing waste waters). Waste Treatment Branch, PNERL-EPA, Corvallis, Oregon.

Brott, Bruce W., and Edwin A. Smith, 1970. Report on proposed wastewater treatment works for the Village of Madison Lake. MPCA, Minneapolis.

Miller, Richard D., 1961. Report on investigation of Madison Lake, Jamestown and LeRoy Townships, Blue Earth County. MN Dept. of Health, Minneapolis.

Schilling, Joel, 1974. Personal communication (lake map, Madison Lake wastewater treatment facility). MPCA, Minneapolis.

Vollenweider, Richard A., (in press). Input-output models. Schweiz A. Hydrol.

VII. APPENDICES

APPENDIX A

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR MINNESOTA 3/18/74

LAKE CODE 2750 MADISON LAKE

TOTAL DRAINAGE AREA OF LAKE 23.80

TRIBUTARY	SUB-DRAINAGE AREA	NORMALIZED FLOWS JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2750A1	23.80	0.29	0.56	3.53	24.10	12.00	14.70	6.47	4.08	2.33	2.54	2.03	0.72	6.11
2750ZZ	23.80	0.32	0.61	3.79	23.80	11.80	14.80	6.42	3.98	2.33	2.48	1.97	0.75	6.08

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 23.80
SUM OF SUB-DRAINAGE AREAS = 23.80

TOTAL FLOW IN = 73.05
TOTAL FLOW OUT = 73.35

MEAN MONTHLY FLOWS AND DAILY FLOWS

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2750A1	10	72	2.50	15	1.50				
	11	72	5.74	5	13.00				
	12	72	1.34	4	2.30				
	1	73	1.54	13	0.60				
	2	73	2.23	4	2.60				
	3	73	14.00	3	7.60				
	4	73	9.88	14	8.30				
	5	73	14.00	28	9.40				
	6	73	4.41						
	7	73	0.60	25	0.56				
	8	73	0.33	29	0.20				
	9	73	0.30						
2750ZZ	10	72	2.45	15	1.40				
	11	72	5.57	5	13.00				
	12	72	1.40	4	2.40				
	1	73	1.70	12	0.60				
	2	73	2.43	4	2.20				
	3	73	15.10	3	8.20				
	4	73	9.76	14	8.20				
	5	73	13.80	28	9.20				
	6	73	4.44						
	7	73	0.64	25	0.60				
	8	73	0.32	89	0.22				
	9	73	0.30						

16

APPENDIX B

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 74/10/30

275001
44 11 48.0 093 48 00.0
MADISON LAKE
27 MINNESOTA

11EPALES 2111202
3 0005 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/07/01	06 40	0000	24.0	6.4	27	300	8.30	126	0.100	0.080	0.102	0.025
72/08/30	10 10	0000			27	275	8.75	125	0.060	0.080	0.041	0.017
	10 10	0004	22.3	10.4		279	8.75	125	0.060	0.080	0.050	0.017
	10 10	0015	19.2	1.0		280	8.45	125	0.080	0.520	0.052	0.020
72/10/29	08 15	0000			44	330	8.20	134	0.170	0.750	0.036	0.017
	08 15	0004	6.1	11.3		330	8.20	134	0.170	0.750	0.044	0.022
	08 15	0010	6.2	11.3		320	8.20	133	0.190	0.760	0.051	0.021

81

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/07/01	06 40	0000	61.4J
72/08/30	10 10	0000	19.8J
72/10/29	08 15	0000	27.2J

J VALUE KNOWN TO BE IN ERROR

STORET RETRIEVAL DATE 74/10/30

275002
44 11 06.0 093 48 20.0
LAKE MADISON
27 MINNESOTA

11EPALES
3

2111202
0021 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/07/01	06 55	0000	23.0	9.4	27	300	8.50	124	0.060	0.080	0.070	0.021
	06 55	0020	20.0	0.3		340	7.60	139	0.150	0.280	0.058	0.017
72/08/30	10 25	0000			36	270	8.65					
	10 25	0004	22.2	9.8		280	8.68					
	10 25	0015	19.7	2.4		285	7.50	126	0.060	0.420	0.038	0.018
	10 25	0022	19.1	0.6		300	7.50	129	0.060	0.700	0.039	0.017
	10 25	0031	17.8	0.2		335	7.20	147	0.170	0.030	0.239	0.122
72/10/29	08 35	0000			40	320	8.20	131	0.180	0.800	0.040	0.016
	08 35	0004	7.0	10.8		310	8.20	131	0.180	0.820	0.054	0.026
	08 35	0015	7.0	10.4		310	8.10	131	0.190	0.830	0.058	0.026
	08 35	0024	7.0	10.4		325	8.10	131	0.180	0.810	0.045	0.023

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/07/01	06 55	0000	33.3J
72/08/30	10 25	0000	13.8J
72/10/29	08 35	0000	29.3J

J VALUE KNOWN TO BE IN ERROR

61

APPENDIX C

TRIBUTARY DATA

STORET RETRIEVAL DATE 74/10/30

2750A1 LS2750A1
44 10 30.0 093 49 00.0
UNNAMED STREAM
27 15 MANKATO EAST
0/MADISON LAKE
RRDG 1.5 MI S OF CITY OF MADISON LAKE
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/15	14 45		0.190	2.000	0.410	0.010	0.060
72/11/05	10 00		0.410	2.900	0.018	0.008	0.072
72/12/04			0.140	0.940	0.092	0.020	0.037
73/01/13	15 00		0.270	2.400	0.755	0.005K	0.035
73/02/04	14 00		0.336	2.360	0.750	0.006	0.055
73/03/03			4.400	2.400	0.890	0.014	0.052
73/03/23	08 30		1.480	4.900	0.005K	0.022	0.140
73/04/14			0.880	4.900	0.330	0.019	0.095
73/05/24			0.880	5.350	0.330	0.023	0.090
73/07/25	18 45		0.010K	2.000	0.033	0.010	0.095
73/08/29	18 30		0.010K	2.700	0.048	0.028	0.150

K VALUE KNOWN TO BE LESS THAN INDICATED

21